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ENERGY REQUIREMENTS FOR WATER TREATMENT SYSTEMS

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Ministry
of the
Environment

The Honourable
George A. Kerr, Q.C.,
Minister

K.H. Sharpe,
Deputy Minister

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Energy Requirements for Water Treatment Systems

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Applied Sciences Section
Pollution Control Branch

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ENERGY REQUIREMENTS FOR WATER TREATMENT EQUIPMENT

A previous technical note(2) examined the energy requirements for wastewater treatment plants in which unit operational energy requirements were tabulated. The idea involved in their utilization was the ability to assess any treatment system on the basis of its total operating energy requirement. Various flow configurations can be examined in this manner to determine a system which can achieve the desired contaminant removal and at the same time keep the energy requirement to a minimum. The purpose of this report is similar to those of the previous studies done by the Applied Sciences Section (1,2). As before, the data are compiled from the literature (3,4,5,6,7,8) and should be utilized in a comparative mode rather than as absolute value data. Some judgement is required in their application coupled with the utilization of the mechanical energy equation for determining pumping requirements. Alternatively, pump and blower curves or manufacturers data may be used.

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1. Zarnett, G.D., "Energy Requirements for Wastewater Treatment Equipment", TN 7008, July, 1976 Applied Sciences Section, Pollution Control Branch, Ministry of the Environment, Ontario.
2. Zarnett, G.D., "Energy Requirements for Conventional and Advanced Wastewater Treatment", Pub. No. W47, Applied Sciences Section, Pollution Control Branch, Ministry of the Environment, Ontario.
3. Smith, R., "Electrical Power Consumption for Wastewater Treatment", EPA Report, R2-73-281, July 1973, U.S. E.P.A., Cincinnati, Ohio.
4. Honea, F.I., Chemical Engineering, 22, 55, Oct. 21, 1974.
5. Peters, H., and Timmerhaus, K.D., "Plant Design Economics for Chemical Engineers", McGraw-Hill Book Pub., N.Y. 1968.
6. Vilbrandt, F.C., and Dryden, C.E., "Chemical Engineering Plant Design", Fourth Ed., McGraw-Hill Co., N.Y. 1959.
7. Chilton, C.H., Chemical Engineering, 58, 3, 115 (1951).
8. Shreve, R.N., "Chemical Process Industries", 3rd Ed., McGraw-Hill Book Co., N.Y. 1967.

THE BASIC ENERGY EQUATION

The calculation of changes in energy resulting from changes in pressure, head, velocity, friction and pumping can

through the use of the mechanical energy equation which may be expressed as:

$$\frac{\Delta\bar{v}^2}{2} + g\Delta z + \int_{P_1}^{P_2} \frac{dP}{\rho} + \ell w_f + \eta_p Ws = 0$$

where: $\bar{v}$ = bulk velocity

z = elevation

P = pressure

ρ = density

ℓwf = lost work due to friction

Ws = shaft work

η_p = pump efficiency

This basic energy balance allows one to calculate the pump energy for most piping and equipment configurations.

PUMPING

Approximations of pumping energy requirements for water pumps may be made as follows:

Pumping Horsepower = $0.1754 \times Q \times H/e_h$

where Q is the water pump influent volumetric flowrate (mgd)
H is the total dynamic head, (ft)
e_h is the hydraulic efficiency

Principal suppliers recommend the following values of hydraulic efficiency, e_h:

up to 1000 gpm = 70% hydraulic efficiency

1000 to 7000 gpm = 74% hydraulic efficiency

over 7000 gpm = 83% hydraulic efficiency

e.g. for an assumption of a total dynamic head of 30 feet of influent pumping, the energy requirements are:

153 kwh/d - 1 mgd

1451 kwh/d - 10 mgd

12,933 kwh/d - 100 mgd

MISCELLANEOUS ELECTRIC MOTORS

Assume an electrical efficiency of 0.877

$\therefore$ KW = 0.85 x HP

ENERGY REQUIREMENTS ACCORDING TO OPERATIONS AND PROCESSES

	Process	Energy	Remarks
AERATION			
	Spray aerators	pumping energy requirement	initial water velocity to be = $C_v\sqrt{2gh}$
	Cascade aerators	low	dependent on pumping requirements
	Multiple-tray aerators	negligible	water pumping energy
	Diffused air aerators	252 kwh/mgd	compressed air with centrifugal compressors 0.01 to 0.15 cu ft/gal
	For specific designs, (9)		

Single Stage Compressor

$$HP = \frac{3.03 \times 10^{-5} k}{k-1} P_1 q_{fm_1} \left[\left(\frac{P_2}{P_1} \right)^{(k-1)\ k} -1 \right]$$

Multistage compressor

$$HP = \frac{3.03 \times 10^{-5} kN_s}{k-1} P_1 q_{fm_1} \left[\left(\frac{P_2}{P_1} \right)^{(k-1)/kN_s} -1 \right]$$

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9 McCabe, W.L., and Smith, J.C. "Unit Operation of Chemical Engineering", 2nd Ed., McGraw-Hill Book Co., N.Y., 1967.

	Process	Energy	Remarks
COAGULATION AND FLOCCULATION			
Pumping requirements			negligible
Chemicals - (production of chemicals)			
	Alum	5.29 kwh/kg	
	Ammonia Alum	9.66 "	
	Sodium Aluminate	9.92 "	
	Ferrous Sulphate	1.54 "	
	Ferric Sulphate	4.08 "	
	Ferric Chloride	1.54 "	
	Lime	1.94 "	
	Kaolin	neg.	
FLOCCULATION (COAGULANT) AIDS			
Adsorbents			
	bentonitic clays	neg.	
	powdered silica	neg.	
	limestone	neg.	
	activated carbon	N/A	
Activated Silica			
	sodium 40°Bé silicate	0.617 kwh/kg	
Polyelectrolytes		low	dependent on manufacturer and chemical composition.

	Process	Energy	Remarks
MIXING AND SEDIMENTATION			
	Horizontially Baffled Mixing Basins	Pumping avg. head loss 2.0 to 3.5 x vel. head for each 180° bend.	usually 1 fps for slightly turbid waters 0.8 fps for low turbidity waters
	Vertically Baffled Mixing Basins		head loss calculated by considering each lower pass as an orifice and each upper pass as a submerged weir.
Mechanical Mixing Basins			
	Mechanical Agitators		
	Mild:	0.37 to 0.75 kw/1000 gal.	
	Vigorous:	1.5 to 2.2 kw/1000 gal.	
	Active:	3.0 to 7.5 kw/1000 gal.	
	Normal:	2.0 kw/1000 gal.	

Power may be calculated from basic equations(9) if more exact values are required.

$$P = \phi Fr^{m} n^{3} D_{a} \rho$$

where: P = power

Fr^{m} = Froude No. = $n^{2} D_{a}/g$

n = rotational speed

D_{a} = diameter of impeller

ρ = density

g = gravitational constant

ϕ = power function, N_{po}/Fr^{m}

N_{po} = power number $P/n^{3} D_{a}^{5} \rho$

and is function of the Reynolds number (Re)

For low Reynolds numbers for baffled and unbaffled tanks,

$$P = K_L n^2 D_a{}^3 \mu$$

where: K_L is a constant(9) dependent on impeller

μ is viscosity

Re > 10,000 for baffled and unbaffled tanks,

$$P = K_T n^3 D_a{}^5 \rho$$

where: K_T is a constant dependent on impeller(9)

	Process	Energy	Remarks
THICKNERS AND CLARIFIERS			
	Gravity sedimentation	none	
	Rectangular settlers (with sludge removal devices)	30.6 kWh/d 122 kWh/d 743 kWh/d	1 mgd, continuous operation 10 mgd, continuous operation 100 mgd, continuous operation
	Circular clarifiers	6.67 to 200 kWh/d	1 mgd, discount 50% for continuous operation
	Thickeners	6.67 to 200 kWh/d	1 mgd, discount 50% for continuous operation
	Dissolved Air Floatation		
	Power consumption for floatation only (10)	75.7 to 170 kWh/(1 mgd)	dependent on floatation time, extra power required due to pumping requirements, particle density, and amount of removal desired.
	Centrifugation	2.0 to 250 kWh/d (1 mgd)	particle density dependent.

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10. Gregory, R., "A Cost comparison Between Dissolved Air Floatation and Alternative Clarification Processes", Paper 11, Session 3, Floatation for Water and Waste Treatment Conference.

	Process	Energy	Remarks
FILTERS			
	Sand Bed	none	gravity flow
	Continuous vacuum filter		
	Belt or Drum	rotation 0.04 kW/ft^2	vacuum 0.5 to 60 cfm/ft^2
	Pressure Filters	low	use pump curve and Ergun equation
	Diatomite Filters		use pump curve and value of pressure drop across bed
	Vacuum Filter (diatomite filter)		vacuum pump surve based on pressure drop across bed

HEAD LOSS IN FILTER (DIATOMITE)

Total Head Loss = head loss in precoat layer + head loss in body feed layer (11)

$$H = K_1 Q W_1 + K_2 C_D Q^2 t \times 8.33 \times 10^{-6}$$

where: H = head loss

Q = rate of filtration

W_1 = weight of precoat

K_1 = permeability of precoat

C_D = concentration of diatomite feed

t = length of filter run

K_2 = permeability of body feed plus suspended layer.

Backwash	see pumping

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11. AWWA Inc., "Water and Quality and Treatment", 3rd Ed. McGraw-Hill Co. N.Y., 1971.

	Process	Energy	Remarks
MASS TRANSFER OPERATIONS			
Distillation and Evaporation			
	Pumping and heating	0.032 to 0.775 kWh/kg	depends on vapour pressure and heat of vapourization of liquid
Electrodialysis			
	D.C. power through stacks	0.491 kWh/1000 gal to 0.85 kWh/1000 gal	
Reverse Osmosis			
	Membranes		
	Cellulose acetate production	N/A	information not released by manufacturer
	Polyamide production	N/A	
	Pumping power	5903 kWh/d @ 1 mgd 55836 kWh/d @ 10 mgd 497811 kWh/d @ 100 mgd	process pressure drop is 500 psig 10% of feed stream wasted with rejected salts
Ion Exchange			
	Zeolites, ion exchangers	N/A	dependent on pump size, frequency of regeneration and type of regenerant

	Process	Energy	Remarks
CHEMICAL OXIDATION AND DISINFECTION			
Oxygen			
	Liquid, small scale 95% contacting system	2.05 kWh/kg 3.88 kWh/kg	dependent on type and contacting efficiency
Ozone			
	Production from generators[12]	6.67 kWh/kg	dependent on type and contacting efficiency
	contacting system		dependent on type and contacting efficiency
Permanganate			
	Potassium permanganate, manganese zeolite application production	N/A	dependent on mixers and proportioning system
Chlorine			
	liquid chlorine production	1.65 kWh/kg	
	evaporation	0.72 kWh/day	1 mgd
		82.4 kWh/day	10 mgd
		226 kWh/day	100 mgd
	chlorine gas	low	
Chlorine Dioxide			
	generation in situ		
	production	2.43 kWh/kg	
Sodium Hypochlorite			
	production	5.60 kWh/kg	

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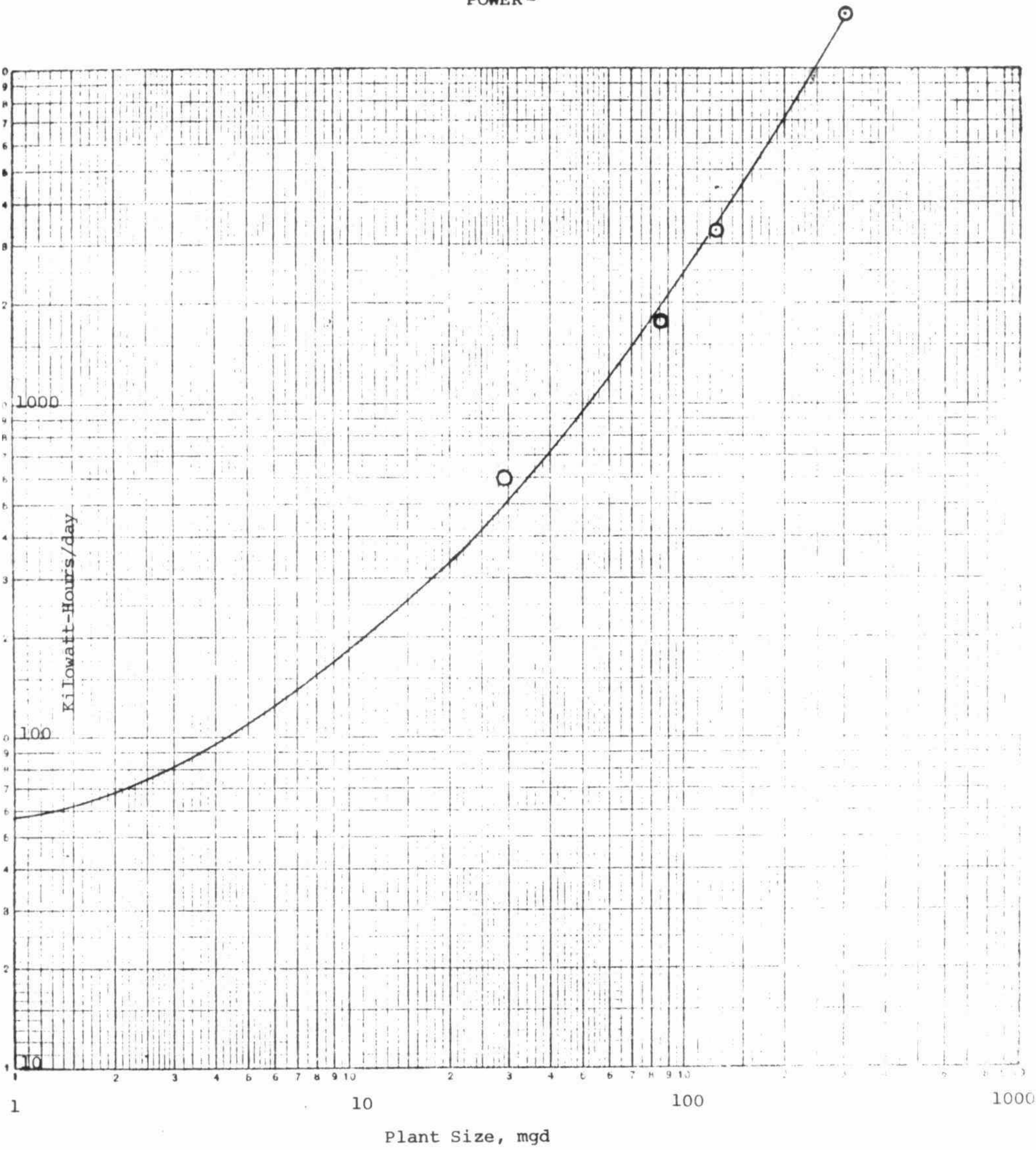
12. Weber, W.J. Jr., "Physiochemical Processes for Water Quality Control", Wiley-Interscience, N.Y., 1972.

	Process	Energy	Remarks
Calcium Hypochlorite			
	production	5.60 kWh/kg	
Hydrogen Peroxide			
	33% production	24.9 kWh/kg	
Ultraviolet Irradiation			
	U.V. Germicidal Lamps	6.67 to 46.2 kWh per million gallons	99% kill for 650 gph to 4500 gph for lamps rated at 30 watts each
OTHER CHEMICALS - ENERGY REQUIRED FOR PRODUCTION			
Dechlorinating Agents			
	sodium bisulphite	0.198 kWh/kg	
	sodium sulphite	0.198 kWh/kg	
	sulphur dioxide (liquid)	7.32 kWh/kg	
pH Adjustment			
	calcium carbonate	14.4 kWh/kg	
	hydrochloric acid	0.0044 kWh/kg	
	sodium hydroxide	2.27 kWh/kg	
	sulphuric acid	0.1874 kWh/kg	
Fluoridation			
	fluospar (CaF)	low	
	hydrofluoric acid	1.17 kWh/kg	
Stabilization			
	sodium tripolyphosphate	0.1896 kWh/kg	
	sodium hexametaphosphate	0.1411 kWh/kg	

	Process	Energy	Remarks
LIGHTS AND MISCELLANEOUS POWER			
	power(3)		see Figure 1.

ELECTRICAL ENERGY REQUIREMENTS FOR LIGHTING AND MISCELLANEOUS POWER[3]



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